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TRAWL MEASUREMENTS

How Canadian East Coast Otter Trawls Behave

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Part of the Fisheries Research Board engineering program on groundfish otter trawls has been to take measurements, with specialized instruments at sea (Fig. 1), of the shapes and force distribution of several commercial types of trawl at several different towing speeds. The highlights of our experimental results are presented here with the belief that they will be useful to some and interesting to many.

One of the most important things shown by these tests and reported in the Appendix is that, as towing speed is increased, the trawl drag increases more rapidly than the speed. The "square law" for the dynamic forces of the water on the moving trawl is essentially true, i.e., twice the speed means four times the hydrodynamic drag, but it is modified slightly by the trawl changing shape as the speed changes. For example, as speed

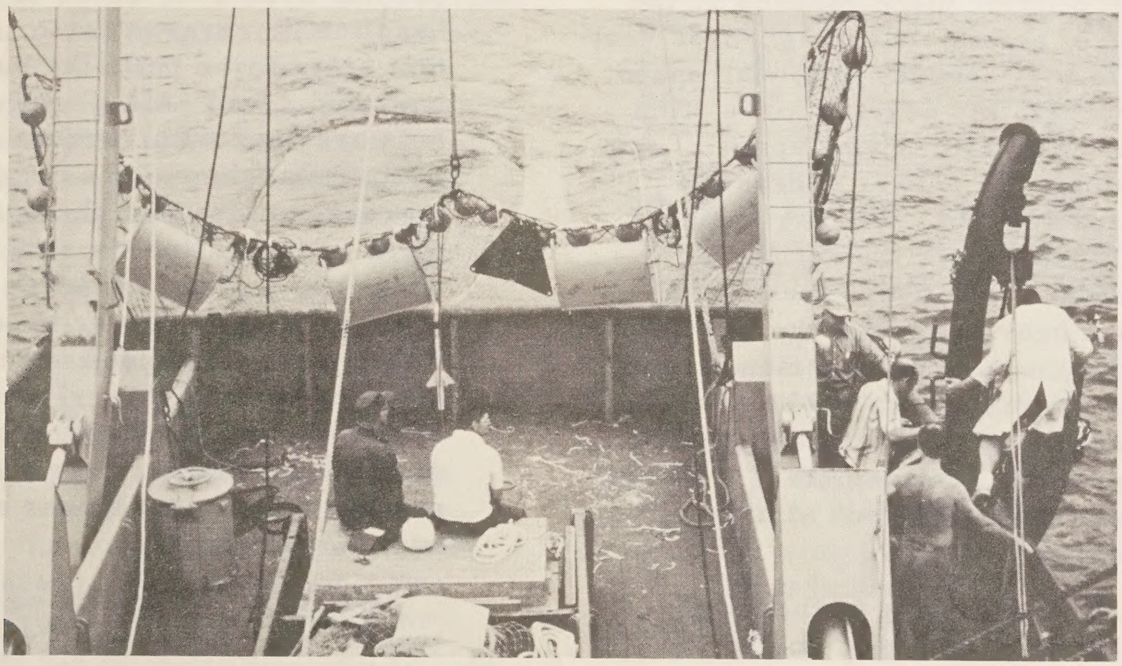

Fig. 1 Headline Instruments Ready and Trawl-Door Instruments Being Prepared for Setting the Trawl.

SOURCES OF DRAG IN A YANKEE 41 TRAWL (No. 3B in Appendix)

SPEED (knots)	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5
GROUND FRICTION (lb.) (nearly constant)	2400	2400	2400	2400	2400	2400
HYDRODYNAMIC DRAG (lb.) (near "square law")	2600	4000	5500	7200	9000	11000
TRAWL DRAG (lb.)	5000	6400	7900	9600	11400	13400

is increased the headline is gradually forced down and the spread of the wings is narrowed. This decreases the angle of the netting to the direction of tow and makes the hydrodynamic drag slightly less than if the trawl had stayed in the same shape.

There are also friction forces against the trawl as it slides along the sea floor, and these increase nearly in proportion to how strongly the trawl presses down against the sea floor. This increase in friction with bearing force depends on the type of sea floor but it changes very little with changes in towing speed. However, the bearing force often does vary with towing speed. For example, at slower speeds the warps sag and have less tendency to lift the doors than at faster speeds. The doors then press more heavily against the sea floor and, as a result, experience more friction drag from the sea floor. The trim of the doors can also be important, for example if it makes them tend to "dig in" at higher speeds.

The total drag of the trawl, which must be overcome by the ship's propulsion, includes both the hydrodynamic drag (approximately "square law") and ground friction (more or less constant) as shown for a typical Yankee 41 trawl in the table above.

Another thing shown by these tests is the way the shape of the trawl mouth changes with changes in towing speed. In most groundfish trawls, a faster towing speed means a lower headline. The headline is held above its points of tow near the sea floor, where the wing bridles join the ground warps (Fig. 2), by constant-buoyancy floats. As a result, when drag-loads on the headline increase at faster speeds, this extra force pulls the headline back and down. Also, when these nets are used with regular rectangular doors, the drag increases more than the spreading force at faster speeds so that the wings are pulled a little closer together than at slower speeds. Thus, as towing speed is increased, both headline height and wing spread decrease, giving a smaller mouth area, and causing the meshes to pull into longer and narrower diamonds.

When the two trawls were tested with oval doors (Trawls 6B and 7B) the wing spread was narrowest at about $3\frac{1}{2}$ knots and increased toward both slower and

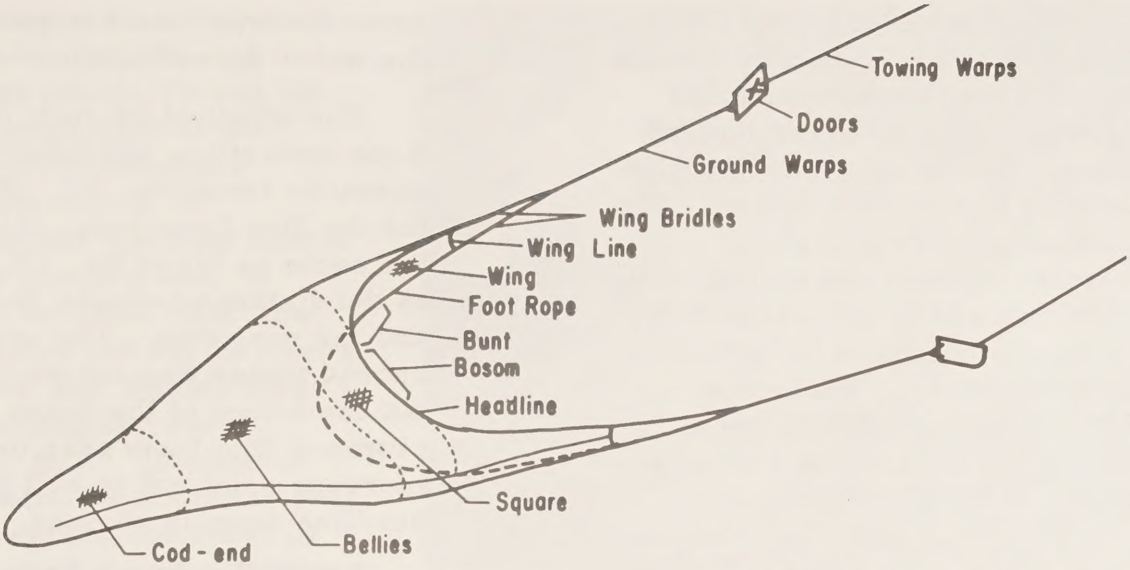

Fig. 2 Groundfish Trawl with Parts Named.

faster towing speeds. Apparently the spreading characteristics of these doors improved at faster towing speeds.

For a particular trawl at a particular towing speed there is a definite relation between wing spread and headline height. Trawls 3A and 3B are the same net, rigged the same except that 3B has a heavier footrope than has 3A. The heavier footrope on 3B causes extra drag, particularly in the bosom of the footrope, and pulls the two wings a little closer together. This lets the headline rise higher. Similarly, fewer floats usually allow the headline to drop and the wings to spread. This definite relation between wing spread and headline height is such that tying on more floats than usual causes very little increase in headline height. The extra floats simply work harder against the footrope and doors, with little change in trawl shape.

The best way to get a higher headline is to put more netting in the width of the square and in the wings, particularly in the bunts, and to lengthen the wing lines accordingly. The effect of more netting in these areas is shown by the Granton trawl (No. 9) whose headline length is about the same as on the Yankee 41 trawls. As a result of the full square and bunts, the Granton headline was about as high as those of the Yankee 41 trawls in spite of its wing lines being only about half as long.

There is no point in making wing bridles longer than three to four times the length of the wing lines. Wing bridles longer than this simply transfer more load onto the wing lines, so that the wing lines hold down the ends of the headline anyway.

The effect of the length of the ground warps is shown by Trawls 4A and 4B which are identical except for ground-warp length. The shorter ground warps pulled the wing tips further apart. The headline also rode higher, possibly because the netting was more exposed to the water flow and was lifted more by hydrodynamic forces. While this larger mouth area may seem desirable, it has been shown in the U.K. that, if the ground warps are spread to too wide an angle (more than about 16° from the direction of tow), their "herding" action decreases and more fish become lost over the ground warps than are gained by the wider spread of the wings.

Fig. 3 Echo-sounder Transducer in Mount for Measuring Headline Height.

The effect of 24-inch Dan Leno butterflies and bobbins is shown by trawl No. 4C. Except for the Dan Leno gear, this is the same as trawl No. 4B, even to the distance between the doors and the wing tips. The wing-spread meter was not working, but the action of the heavy and cramped Dan Leno gear to increase drag and to pull the headline down is obvious.

Trawl No. 5 is a Yankee 41 made of bitumen-treated nylon netting, which is slightly heavy in the water (100 lb. air-dry netting weighs about 9.3 lb. when immersed and soaked in sea water) in contrast with the buoyant netting used in all the other trawls. The headline-height meter was not working, but this trawl was shown to have a narrower wing spread than corresponding polyethylene trawls, even though the ground warps were shorter. On average, this trawl has less drag than the polyethylene Yankee 41 trawls in spite of heavier netting and heavier doors, perhaps because the ground warps were shorter and the footrope lighter. These structural differences between the trawls mean that a deeper analysis of the test results will have to be made before the true differences between the characteristics of treated nylon netting and polyethylene netting are revealed.

A comparison between trawls 6A and 6B and between trawls 7A and 7B gives some idea of the relative performance characteristics of rectangular and oval doors. In this comparison, it should be noted that the oval doors (30 sq. ft.) were smaller and lighter than the rectangular doors (43 sq. ft.). In spite of their smaller size, the oval doors spread the trawl as well as did the rectangular doors at normal towing speeds, displaying their greater hydrodynamic efficiency. The oval doors also produced a slightly higher headline. With oval doors, the drags of the trawls were less than with the rectangular doors, partly because the oval doors were lighter and experienced less friction against the sea floor, and partly because they were designed to have less hydrodynamic drag.

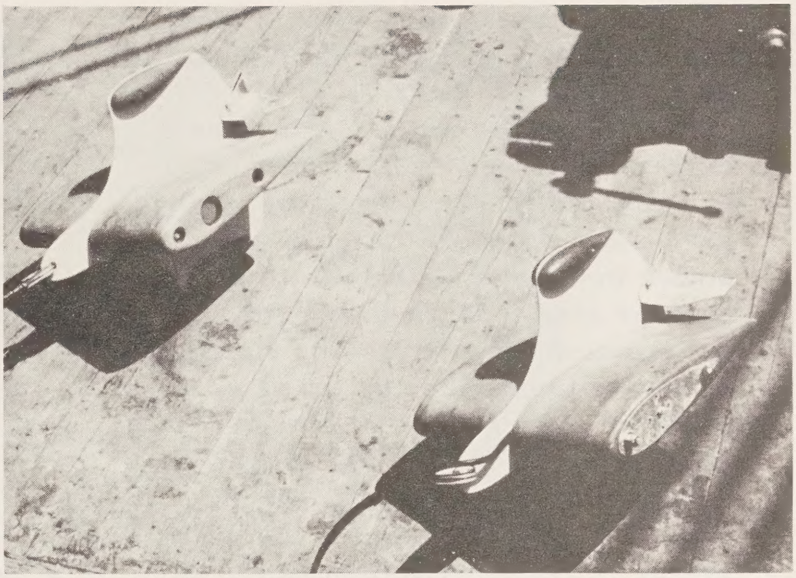

Fig. 4 Echo-sounder Transducers in Wing Floats for Measuring Spread of Trawl Mouth.

A comparison between trawls 6A and 7A and between trawls 6B and 7B tells something about treated Ulstron netting, which is slightly less buoyant (100 lb. netting is about 5.7 lb. buoyant in sea water) than polyethylene netting (100 lb. netting is about 6.8 lb. buoyant in sea water). On average, the treated Ulstron trawls towed slightly narrower and higher, and had slightly less drag than did the polyethylene trawls.

The Skagen trawl (No. 8) is a "Vinge" trawl whose headline has about the same length as that on a Yankee 41. The forward ends of the lower wings are left open. The wing lines are very long (over 40 ft.) and the wing bridles are correspondingly long, presumably to allow the headline to rise. However, the headline was lower than in the Yankee 41 trawls, probably partly because there was very little more netting in the width of the square and in the aft parts of the wings to let the headline rise and partly because there was considerably more netting in the bellies and cod-end, with more drag to pull the headline down. It may be possible to raise this Skagen headline a little by adding more floats, but this would probably also require a heavier footrope. The relatively narrow spread between the wings of this trawl is largely a consequence of the relatively long bridles and ground warps.

The Granton trawl (No. 9) also has a headline length about the same as a Yankee 41, but it is a larger net in that it has more netting and a longer footrope. This greater size is reflected in a greater drag at any particular speed, requiring more power for towing. Despite this greater size, the mouth opening of the Granton trawl was very similar to that of the Yankee 41 trawls --- headline slightly higher, wing spread slightly less. This trawl has been designed for relatively rough grounds and the heavier construction for greater durability in turn requires heavier handling equipment.

The Atlantic Western III trawl (No. 10) is a four-side-seam net designed for a high mouth opening. The length of the headline is about the same as on a Yankee 41, but the side panels permit wing lines about three times as long as on the "41". Like the Granton, this trawl has a long footrope and a lot of netting, resulting in more drag than a "41" at the same speed. The net had good headline height, but the wing spread was disappointing. Probably larger doors and shorter ground warps would help to increase this spread, if desired.

So far, the "speed" referred to has been the speed of the trawl-net through the water. If there is an ocean current against the direction of tow at the trawl, hydrodynamic drag will be increased. If the ship's propulsion does not overcome this increased drag, the ship and trawl will move more slowly over the sea floor. Similarly, if the ocean current is with the direction of tow at the trawl, hydrodynamic drag decreases and towing speed increases unless the engine speed is reduced. Generally, the speed of the ocean current at the trawl is less than at the vessel, but frequently it is in a different direction. With such currents, the speed of the vessel through the water, as measured by a ship's log, can be very misleading, but the methods available for measuring the speed of the trawl through the water directly (see Fig. 5) are too awkward to use during commercial fishing operations. Winds and ocean currents, in addition to affecting the performance of the gear, may also help or hinder the ship's propulsion in its effort to tow the trawl, depending on their directions.

In this complex of forces, one of the easiest ways to be sure that the trawl is properly set and is being towed at the best speed (in relation to the water at the trawl) is by measuring the tensions in the two warps. If these tensions are unequal, either the warps have different lengths (perhaps stretched), or the doors are balanced differently or are riding differently, or there is a cross current. If the warp tensions are too high or too low, so is the engine speed, and appropriate adjustment can be made, as indicated by the tension meters, to adapt to various current and wind conditions. Warp tension meters also give some warning of hang-ups and can be coupled with an automatic alarm. However, if warp tensions are to be used for estimating the amount of catch, then the tension-meter readings have to be combined with direct and accurate measurements of the speed of the trawl through the water,

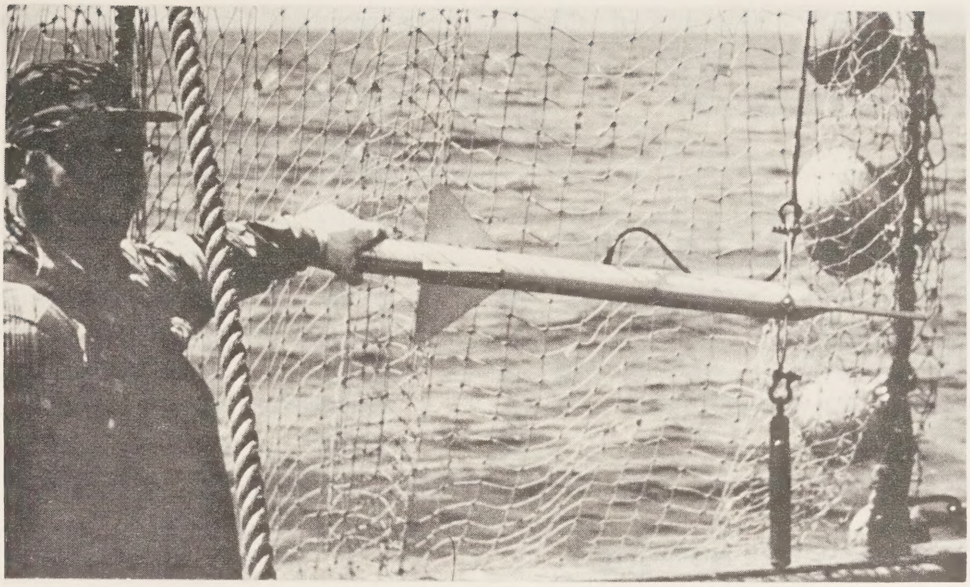

Fig. 5 Pitotmeter for Measuring Hydrodynamic Pressure and, hence, Speed of Trawl through Water.

also taking the type of sea floor into account, and this is not very practical. The average warp tensions, as reported in the Appendix, are greater than half the total trawl drag because the weight of the warps in the water, the upward pull of the warps on the doors, and the spreading force from the doors all help to increase the warp tension, whereas only the drag acting opposite to the direction of tow needs to be overcome by the ship's propulsion.

A full discussion of trawl engineering would have to be much longer than this. Further information can be obtained by a detailed analysis of these data, which is being undertaken now, but some additional information, such as trawl specifications and detailed measurements from each tow, is reported in the Fisheries Research Board of Canada Technical Report No. 125.

APPENDIX - Measured Characteristics of Groundfish Otter Trawls

	Trawl Type and Rigging	Speed (knots)	Trawl Drag (lb)	Wing Spread (ft)	Headline Height (ft)	Warp Tension (lb)
1	YANKEE 35 POLYETHYLENE					
	Doors: 3.5x6.5 ft. - 450 lb.	2½	2300	28	6.9	1300
	Rectangular	3	2900	28	6.8	1600
	Ground Warps: 90 ft.	3½	3500	28	6.8	1900
	Wing Bridles: 30/31 ft.	4	4400	29	6.7	2400
	Floats: 18x8-in.	4½	5500	29	6.2	2900
	Footropes: 4-in. Discs					
2	YANKEE 36 POLYETHYLENE					
	Doors: 4.1x7.5 ft. - 700 lb.	2½	2800	34	10.1	1500
	Rectangular	3	3600	34	9.3	2000
	Ground Warps: 120 ft.	3½	4500	34	8.6	2500
	Wing Bridles: 30/31 ft.	4	5700	33	8.0	3000
	Floats: 30x8-in.					
	Footrope: 16-in. Rubber					
3A	YANKEE 41-5 POLYETHYLENE					
	Doors: 4.5x10 ft. - 1600 lb.	2½	5400	44	8.3	2800
	Rectangular	3	6400	43	7.6	3400
	Ground Warps: 180 ft.	3½	7700	43	7.1	4000
	Wing Bridles: 31/30 ft.	4	9200	43	6.7	4900
	Floats: 46x8-in.	4½	10900	43	6.4	5900
	Footrope: 7-in. Discs	5	13000	43	6.2	6900
3B	YANKEE 41-5 POLYETHYLENE					
	Doors: 4.5x10 ft. - 1600 lb.	2½	5000	43	9.9	2700
	Rectangular	3	6400	43	8.9	3400
	Ground Warps: 180 ft.	3½	7900	43	8.1	4300
	Wing Bridles: 31/30 ft.	4	9600	43	7.5	5200
	Floats: 46x8-in.	4½	11400	42	7.2	6100
	Footrope: 18-in. Rubber	5	13400	42	6.9	7100
4A	YANKEE 41-5 POLYETHYLENE					
	Doors: 4.5x10.5 ft. - 1700 lb.	2½	-	44	10.8	4000
	Rectangular	3	8500	43	10.6	4600
	Ground Warps: 180 ft.	3½	9700	43	10.3	5300
	Wing Bridles: 31/30 ft.	4	11100	43	9.9	6100
	Floats: 50x8-in.	4½	13000	43	9.7	7100
	Footrope: 21-in. Rubber	5	15300	43	9.4	8200

Trawl Type and Rigging	Speed (knots)	Trawl Drag (lb)	Wing Spread (ft)	Headline Height (ft)	Warp Tension (lb)
4B YANKEE 41-5 POLYETHYLENE					
Doors: 4.5x10.5 ft. - 1700 lb.	$2\frac{1}{2}$	6400	48	12.3	3500
Rectangular	3	7700	47	11.8	4200
Ground Warps: 120 ft.	$3\frac{1}{2}$	9300	47	11.3	5000
Wing Bridles: 31/30 ft.	4	11000	47	10.9	6000
Floats: 50x8-in.	$4\frac{1}{2}$	13000	46	10.6	7000
Footrope: 21-in. Rubber	5	15200	46	10.4	8200
4C YANKEE 41-5 POLYETHYLENE					
Doors: 4.5x10.5 ft. - 1700 lb.	$2\frac{1}{2}$	-	-	-	-
Rectangular	3	8000	-	9.8	4300
Ground Warps: 138 ft.	$3\frac{1}{2}$	9700	-	9.4	5200
Bridles: 7/6 ft. + Dan Leno	4	11600	-	9.0	6300
Floats: 50x8-in.	$4\frac{1}{2}$	13700	-	8.7	7400
Footrope: 21-in. Rubber	5	16100	-	8.4	8700
5 YANKEE 41-5 TREATED NYLON					
Doors: 4.5x10.5 ft. - 1800 lb.	$2\frac{1}{2}$	5800	43	-	3100
Rectangular	3	7100	43	-	3800
Ground Warps: 90 ft.	$3\frac{1}{2}$	8700	43	-	4600
Wing Bridles: 31/30$\frac{1}{2}$ ft.	4	10600	42	-	5600
Floats: 68x8-in.	$4\frac{1}{2}$	12900	41	-	6700
Footrope: 18-in. Rubber	5	15600	40	-	8100
6A YANKEE 41 POLYETHYLENE					
Doors: 4.5x9.5 ft. - 1600 lb.	$2\frac{1}{2}$	5600	51	8.7	3100
Rectangular	3	6900	49	8.4	3700
Ground Warps: 180 ft.	$3\frac{1}{2}$	8300	48	8.1	4500
Wing Bridles: 31/30 ft.	4	10000	47	7.9	5400
Floats: 43x8-in.	$4\frac{1}{2}$	11900	46	7.8	6500
Footrope: 18-in. Rubber	5	14000	46	7.8	7800
6B YANKEE 41 POLYETHYLENE					
Doors: 4.7x8.0 ft. - 1430 lb.	$2\frac{1}{2}$	5200	46	10.5	2900
BMV-Oval	3	6200	45	9.8	3400
Ground Warps: 180 ft.	$3\frac{1}{2}$	7300	43	9.5	3900
Wing Bridles: 31/30 ft.	4	8700	44	9.2	4700
Floats: 43x8-in.	$4\frac{1}{2}$	11400	46	8.7	5900
Footrope: 18-in. Rubber	5	13800	50	-	7400

Trawl Type and Rigging	Speed (knots)	Trawl Drag (lb)	Wing Spread (ft)	Headline Height (ft)	Warp Tension (lb)
7A YANKEE 41 TREATED ULSTRON					
Doors: 4.5x9.5 ft. - 1600 lb.	$2\frac{1}{2}$	6100	52	10.1	3400
Rectangular	3	7200	49	9.6	3900
Ground Warps: 180 ft.	$3\frac{1}{2}$	8500	47	9.3	4500
Wing Bridles: 31/30 ft.	4	9900	45	9.0	5300
Floats: 19x8-in. + 48x7-in.	$4\frac{1}{2}$	11800	44	8.9	6400
Footrope: 18-in. Rubber	5	14700	44	8.8	7900
7B YANKEE 41 TREATED ULSTRON					
Doors: 4.7x8.0 ft. - 1430 lb.	$2\frac{1}{2}$	5000	46	11.2	2700
BMV-Oval	3	5900	44	10.6	3200
Ground Warps: 180 ft.	$3\frac{1}{2}$	7000	42	10.2	3800
Wing Bridles: 31/30 ft.	4	8600	42	9.7	4600
Floats: 19x8-in. + 48x7-in.	$4\frac{1}{2}$	11000	46	9.0	5800
Footrope: 18-in. Rubber	5	13300	-	-	7100
8 SKAGEN POLYETHYLENE					
Doors: 4.5x10 ft. - 1600 lb.	$2\frac{1}{2}$	5100	41	9.4	2900
Rectangular	3	6300	41	8.6	3400
Ground Warps: 180 ft.	$3\frac{1}{2}$	7500	40	8.0	4100
Wing Bridles: 120 ft.	4	9000	40	7.5	4800
Floats: 36x8-in.	$4\frac{1}{2}$	10500	40	7.1	5700
Footrope: Rounded	5	12800	41	6.9	6900
9 GRANTON POLYETHYLENE					
Doors: 4.5x10.5 ft. - 1700 lb.	$2\frac{1}{2}$	-	50	-	-
Rectangular	3	7500	46	-	4100
Ground Warps: 120 ft.	$3\frac{1}{2}$	9200	44	9.3	5000
Wing Bridles: 31/30 ft.	4	11100	43	9.4	6200
Floats: 56x8-in.	$4\frac{1}{2}$	13400	42	9.5	7400
Footrope: 21-in. Rubber	5	-	42	-	-
10 ATLANTIC WESTERN III					
Doors: 4.5x10 ft. - 1600 lb.	$2\frac{1}{2}$	6400	36	15.6	3300
Rectangular	3	7900	35	14.7	4100
Ground Warps: 180 ft.	$3\frac{1}{2}$	9500	35	13.9	4900
Wing Bridles: 91/90 ft.	4	11300	35	13.3	5900
Floats: 77x8-in.	$4\frac{1}{2}$	13400	36	12.7	7100
Footrope: 21-in. Rubber	5	15700	37	12.3	8500

NOTES